



REPORT: OPTIMIZATION AND CIVIL ENGINEERING
Minimizing Reinforcing Bar-Cutting Waste for Sustainable
Construction (South Korea)

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THANK YOU!

ABSTRACT: In search for a subject for my research, my idea was to see how I am as a civil engineer could save our planet from climate change and reduce toxic waste during the construction phase. I was eager to find such an algorithm to reduce the CO₂ emissions as much as possible to ensure the sustainability of our eco-system. In the previous semester, we studied the environmental management and it opens my eyes to try to innovate in order to reduce those emissions. To reduce the emitted carbon dioxide in the architecture, engineering, and civil industry, it is extremely effective to lower the CO₂ emissions from all materials that consume significant amounts of energy and emit a high proportion of greenhouse gases. Therefore, I have found a very interesting algorithm that reduce the waste of cutting rebar during the construction and we will show how much it reduces of CO₂ emissions and the cost saving by the CWM.

¹CWM: Cutting waste minimization

I. Introduction

Reinforcing bars, as known as Rebar, is a steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and aid the concrete under tension. It intensify significantly the tensile strength of the structure.

Rebar have the most embodied carbon dioxide per unit of weight in built environments. It generates a significant amount of CO₂ emissions and that because of the excessive cutting waste generated during the construction phase. Not only it pollutes the environment but also it costs extra for the wastage of steel at hand.

Concrete and reinforcing steel contribute about 65% of building greenhouse gases (GHG), 40% of which are CO₂ emissions generated by concrete [1]. This suggests that reducing the mean of embodied carbon dioxide ECO₂ in the structural frame directly produces a GHG reduction. In addition, in terms of the carbon footprint, efforts to reduce the rebar, which has an ECO₂ of about 9.2 times that of concrete per unit weight [2], are crucial to sustain an our ecosystem.

The aim of this report is to bring to light an algorithm that minimizes the wastage of steel cut scarp. Many studies have been conducted to solve this problem, knowing that the acceptable waste varies from 3 to 5% in the planning stage, but the reality is more than that and that because of how inaccurate the used algorithms. The use of *special lengths for cutting waste* minimization (CWM) in the construction industry is lacking.

As we are about to show at what follows, we will discuss (CWM) algorithms for rebar and the how it reduces the CO₂ emissions.

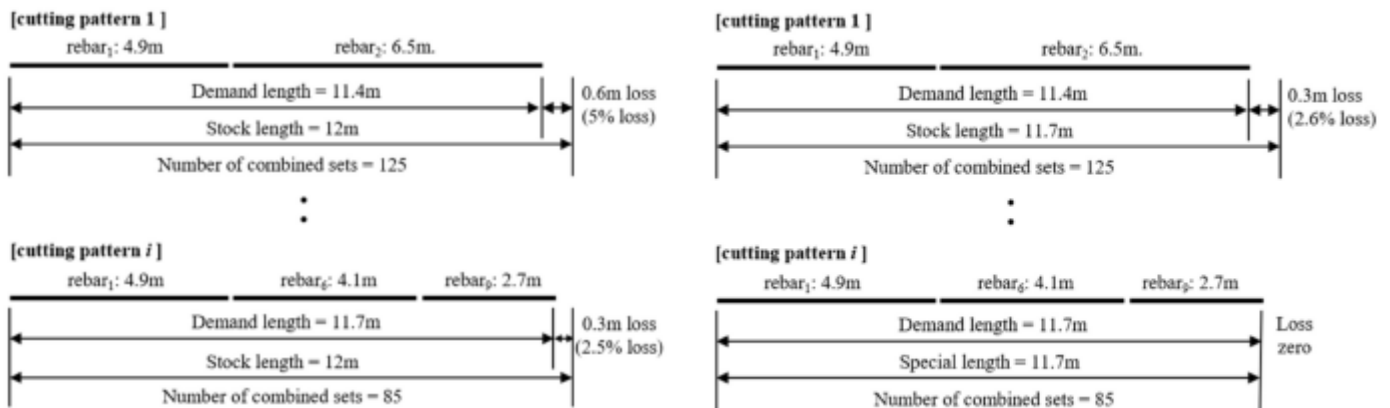
II. Cutting Waste Minimization Algorithms

1. Definitions

- Special length: the length determined by the customer's order, not the rebar length sold on the market.
- Stock lengths: the length is already determined by the supplier (which may differ between countries)

There are two types of CMW methods. First, the minimization by stock length (MStL) and the minimization by special length (MSpL). The two of them require some constraint as the target loss ratio and minimum quantity. Multiple combination of special length and stock length in different patterns have been used in both methods with a quite difference in waste loss as shown in figure 1a and 1b.

Figure 1.



1a. Combination cases of stock length

1b. Combination cases of special lengths.

2. Cutting Waste Minimization (CWM)

a. How to proceed?

The aim is always reducing as much as possible the waste of rebar, either by (MStL) or (MSpL). For instance, figure 1b shows that the (MSpL) reduce the loss to its minimum but in practice, we don't have that option as preferable as you may ask. Thereby we will proceed as the figure 2:

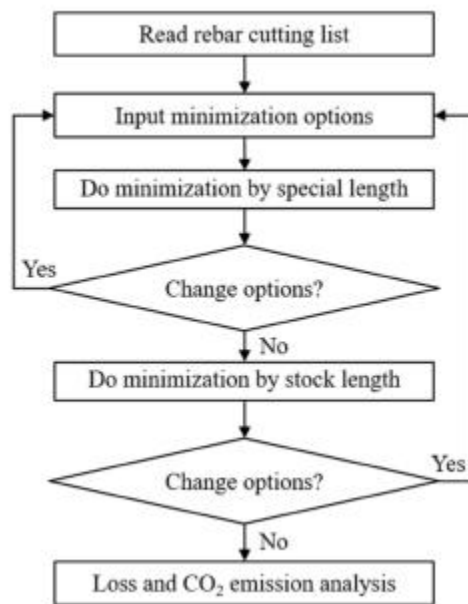


Figure 2. Cutting waste minimization chart

b. The algorithm of (MStL)

In the construction sector, the manufacturer in market lengths supplies materials such as rebar, structural steel, pipes, and timber. That's why we perform the (CWM) on stock lengths as follows:

$$\text{Minimize} \left(\sum_{i=1}^N \frac{Lst_i n_i - l_i n_i}{Lst_i n_i} \right) \quad (1)$$

$$l_i \leq Lst_i, \quad l_i = \sum_{i=1}^n r_i \quad (2)$$

$$L_{\min} \leq Lst_i \leq L_{\max} \quad (3)$$

$$n_i > 0, \text{ integer}, \quad i = 1, 2, \dots, N \quad (4)$$

Where:

- Lst_i : Stock length of cutting pattern i (m)
- l_i : Length of cutting pattern i obtained by combining multiple rebars, demand lengths (m)
- n_i : Number of rebar combinations with the same cutting pattern i

- r_i : Length of combined rebar (m)
- $L_{\min}$: Minimum length of rebar to be ordered (m)
- $L_{\max}$: Maximum length of rebar to be ordered (m).

Note that :

- The equation (1) is a mathematical formulation that minimizes the difference between the length of the cutting pattern l_i and the stock length Lst_i obtained by combining multiple rebars (as shown in figure 1).
- The equation (3) is redundant if we used only one stock length.
- This algorithm doesn't assure us the optimization wanted yet.

c. The algorithm of (MSpL)

The formulation is the same as the previous algorithm with taking into account the rate loss $\varepsilon = \frac{Lsp_i - l_i}{Lsp_i}$, the target loss rate ε_t and minimum quantity for special order Q_{s_0} (ton) that must be searched (the minimum quantity to be ordered).

$$\text{Minimize} \left(\sum_{i=1}^N \frac{Lsp_i n_i - l_i n_i}{Lsp_i n_i} \right) \quad (5)$$

$$l_i \leq Lsp_i, l_i = \sum_{i=1}^n r_i \quad (6)$$

$$L_{\min} \leq Lsp_i \leq L_{\max} \quad (7)$$

$$Q_{s_0} \leq Q_{tot} \quad (8)$$

$$n_i > 0, \text{ integer}, i = 1, 2, \dots, N \quad (9)$$

Where:

- l_i : Length of cutting pattern i obtained by combining multiple rebars, demand lengths (m)
- Lsp_i : Special length of cutting pattern i that satisfies the target loss rate (m)
- $L_{\max}$: Minimum length of rebar to be ordered (m)
- $L_{\min}$: Maximum length of rebar to be ordered (m)
- n_i : Number of rebar combinations with the same cutting pattern i

- r_i : Length of combined rebar (m)
- ε : Cutting waste or loss rate (%)
- ε_t : Target cutting waste or loss rate (%)
- Q_{tot} : Total combined rebar quantity (ton)
- Q_{s_0} : Minimum rebar quantity to be special ordered (ton).

➤ **How we can implement this linear algorithm?**

It's not a straightforward technic, we will give an example and a pseudocode to get the desired optimization. For example, in the case where the loss rate is less than 2%, the length is between 8 and 12 m at intervals of 0.1 m, but the total quantity (Q_{tot}) of the same length that will be more than 50 tons is searched. The MSpL that satisfies these conditions proceeds with the process shown in Figure 3. The minimization process in that figure is described in pseudocode, as follows: (This is exactly as described in the source I took it from without any furnishing from my side because it explains precisely how we should proceed)

- i. After the rebar cutting list is read, in which the number of reinforcing bars by diameter and length is counted, it is sorted in descending order with length and number priority. This is for efficient performance of the **quantity–priority combination**.
- ii. Options as L_{max} , L_{min} , Q_{tot} , ε_t , etc.. are entered.
- iii. The rebar combination l_i that satisfies $L_{min} \leq Lsp_i \leq L_{max}$ for rebar of the same diameter is executed in descending order from the maximum length L_{max} of rebar to

be ordered. If $\frac{Lsp_i - l_i}{Lsp_i} \leq \varepsilon_t$ is satisfied, the next combination $i = i + 1$ is executed

until the end of the list after saving the result of combination, or the combination is performed until the loss rate condition is satisfied. This is because executing the combination in descending order from the maximum length is effective in performing the quantity–priority combination, as described in step (1).

- iv. Next, the total quantity of combined rebar is calculated by the equation (10):

$$Q_{tot} = \varpi \sum_{i=1}^N Lsp_i n_i \quad (10)$$

where, ϖ : unit weight of combined rebar per meter (ton/m).

- v. If $Q_{s_0} \leq Q_{tot}$ is not satisfied, MSpL is repeated while Lsp_i is decreased by 0.1 m until $Lsp_i \leq L_{min}$ is satisfied. If a solution that satisfies the constraints is not found in the process so far, it should be decided whether to perform the minimization again after alleviating the combination conditions. Otherwise, MStL must be subsequently performed.

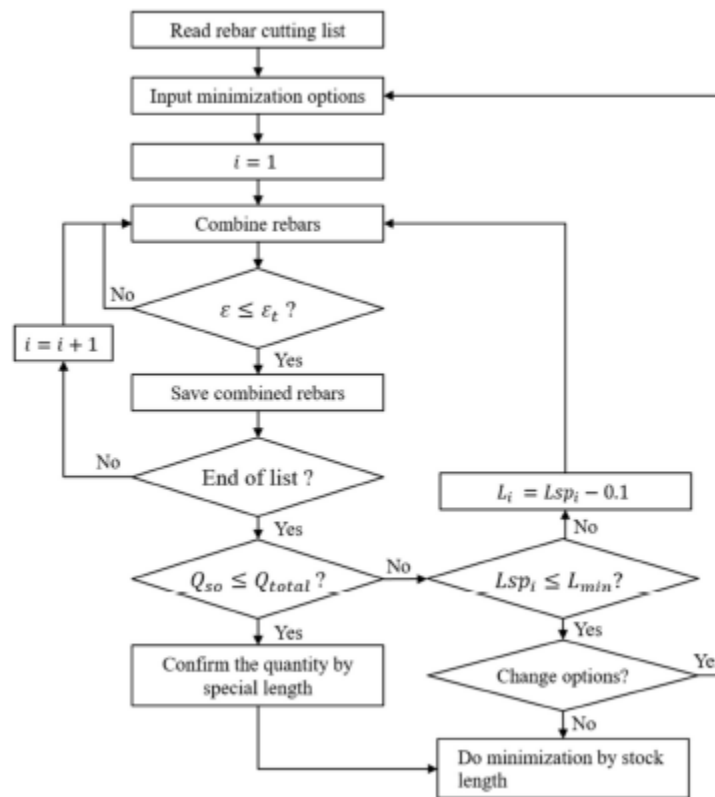


Figure 3

III. Application of CWM Algorithms

1. Description of the case project

The case project shown in Table 1 was selected in this study. This is a commercial building project constructed in Seoul, Korea, with a total floor area of 66,644 m², three basement levels, and 20 floors above ground. The structure of the case building, the underground structure is steel reinforced concrete (SRC) and the superstructure is reinforced concrete (RC). In addition, the first and second floors are designed as a column-and-beam structure, and as shown in Figure 4, from the 3rd floor to the 20th floor, it is designed as a flat slab structure.

Description	Contents
Location	Seoul, Korea
Site area	8832 m ²
Building area	3970 m ²
Total floor area	66,644 m ²
No. of floors	B3 to F20
Structure	Basement: SRC Superstructure: RC

Table 1

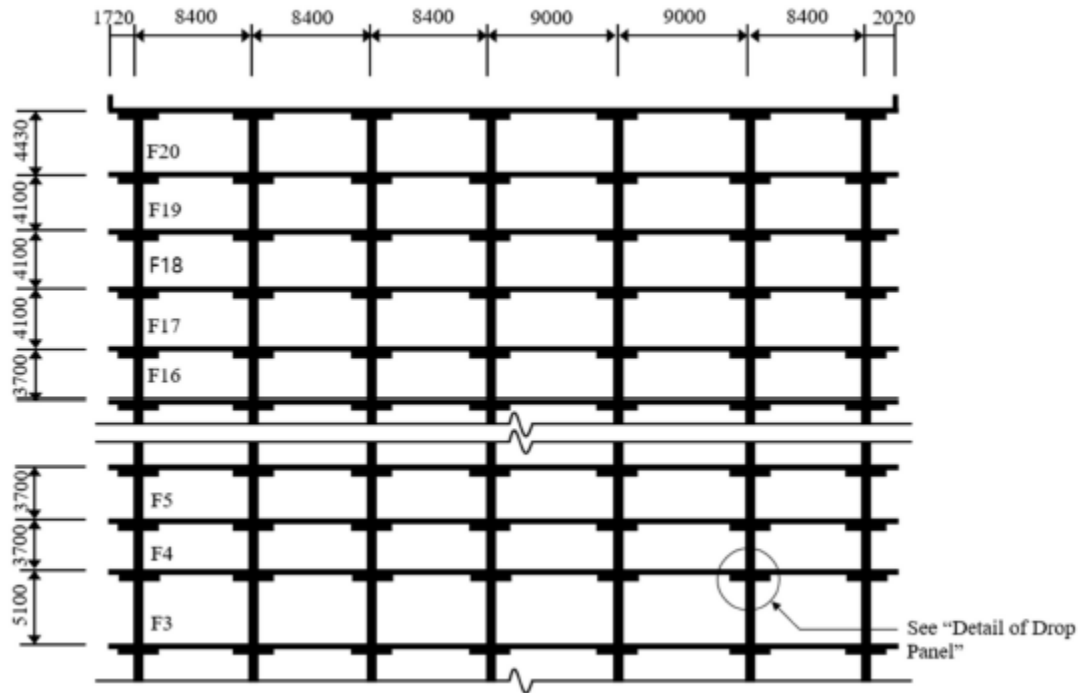


Figure 4: Structural frame of the case building.

NB: Other details are not necessary for this report.

For the columns of the case project, the table 2 give the rebar details knowing that the used bars had optimized according to the change in the load condition of each floor.

Floor	F3 to F8	F9 to F10	F11 to F13	F14 to F20
Column section				
Main bars	26-D25	26-D25	16-D25	14-D25
Hoop	Mid	D10@250	D10@250	D10@250
	End	D10@200	D10@200	D10@200

Table 2

Here in Morocco we use the notation HA instead of D to refer to deformed bars.

2. Application of CWM algorithms

In this study, for the verification of the proposed algorithm, rebar combinations were performed on structural frames from F3 to F20. The rebar cutting list generated from the bar-bending schedule was used for rebar information. Tables 3 and 4 show the combination results of the CWM algorithms for the main bars of all of the columns.

Combination Report for Special Lengths						
Diameter (mm) = 25		Reference files = proj101_bcl.dat				
Combination conditions		Min. length (m) = 6.0		Max. length = 10.0		
		Min. weight (ton) = 50		Max. loss rate (%) = 3.0		
Cutting Pattern	No. of rebars	Combined Length (m)	Order Length (m)	Combined Weight (ton)	Order Weight (ton)	Loss Rate (%)
S1	6121	7400	7400	176.20	176.20	0.00
S2	1196	9200	9200	42.80	42.80	0.00
S3	526	8,530	9200	17.45	18.82	7.85
Sum				236.45	237.82	0.58

Table 3

Combination Report for Stock Lengths						
Diameter (mm) = 25		Reference files = proj101_bcl.dat				
Combination conditions		Min. length (m) = 6.0		Max. length = 10.0		
		Min. weight (ton) =		Max. loss (%) = 3.0		
Cutting Pattern	No. of Rebars	Combined Length (m)	Stock Length (m)	Combined Weight (ton)	Stock Weight (ton)	Loss Rate (%)
N1	48	8.860	9.000	1.65	1.68	1.58
Sum				1.65	1.68	1.58

Table 4

Discussion.

The tables show the results of MSpL and MStL according to the associated linear algorithm. We note that the loss rate of the final MSpL is 0.58%, which corresponds to 1.37 tons of cutting waste. Table 4 brings to light the results of MStL by Equations (1) to (4), and the final loss rate is about 1.58%. For reference, in the case of MStL, the combination conditions are the same as for MSpL but the minimum weight is not specified. This is because it is assumed that there is a sufficient quantity in stock.

Comparing the loss rate obtained by the two algorithms, it is clear that the MSpL deliver a better minimization of the cutting waste. This is because combination by special length is performed to further reduce the loss rate.

Table 5 shows the results of applying CWM algorithms to all types of rebar used in the case structural frame in Figure 4. Five diameters of rebar were used, and a total loss rate of 0.96% was calculated. The total quantity of rebar required for construction is

1.807.45 tons, and the quantity to be supplied in special and stock lengths is 1.824.75 tons. The loss rate is different for each diameter of rebar depending on the design characteristics of the structural member in which each rebar is used. The details are as follows:

Description	Unit	D10	D13	D16	D19	D25	Sum
Combined weight (C)	ton	335.62	899.93	259.94	73.86	238.10	1.807.45
Supply weight (S)	ton	338.29	906.03	264.01	76.92	239.50	1.824.75
Loss rate (S-C)/S	%	0.80	0.68	1.57	4.14	0.59	0.96

Table 5

3. Comparison of Actual and Optimized Rebar Quantities

In order to see what the CWM algorithms bring to the case, we must compare the actual and optimized rebar quantities. Table 6 shows in details the comparison with the reduction rate of the actual and optimized quantities.

As you may know that rebar with small diameter had only secondary use so it's reasonable to have a small reduction rate. However, we have 10.27% for D10 which is higher than D13, D16 and D25: It is presumed to be a problem with the rebar work management. Other observation are interesting to mention, note that the D25 is the main rebar used in columns and it is relatively easy to manage the rebar to reduce cutting waste because there are not many changes in length.

Description	Unit	D10	D13	D16	D19	D25	Sum
Actual (A)	ton	377.00	952.43	276.00	87.80	248.82	1.942.05
Optimized (O)	ton	338.29	906.03	264.01	76.92	239.50	1.824.75
Quantity reduction (A-O)	ton	38.71	46.40	11.99	10.88	9.32	117.30
Reduction rate (A-O)/A	%	10.27	4.87	4.34	12.39	3.75	6.04

Table 6

For reference, when the reduced rebar quantity of 117.3 tons is converted into money, it is about USD 98,976 including material, cutting and bending, and placement costs.

4. The environmental side of the CWM

The purpose I chose this algorithm is its liaison with the reduction of CO₂ emissions. The CWM algorithms aims to reduce the wastage of cutting bars and therefore the contribution to a sustainable construction.

Note that 3.466 ton-CO₂/ton, the unit CO₂ emissions of high-tensile deformed bar published by the Korea Institute of Construction Technology (KICT). (the unit depends on the country). Table 7 shows the calculation of CO₂ emissions reduction effect:

Description	Quantity (ton)	Unit CO ₂ Emission (ton-CO ₂ /ton)	Amount (ton-CO ₂)
Actual (A)	1.942.05	3.466	6.731.15
Optimized (O)	1.824.75	3.466	6.324.58
Reduction effect (A–O)	117.30		406.60

Table 7

When the CWM algorithms are applied, it can be seen that the case project has a CO₂ emission reduction of 406.60 tons which is equivalent to 6.04% of the structure. As mentioned in the introduction, in the case of buildings, the structure accounts for about 65% of building GHGs. Considering this reference, there is a CO₂ emission reduction of 3.93% based on the whole building.

From a carbon footprint point of view, the embodied CO₂ per unit weight or volume of rebar is about 9.02 times that of concrete ; therefore, the CO₂ emission reduction produced by the CWM algorithms has a *great effect on sustainable construction*.

IV. Is the CWM is applicable in Morocco?

As we have seen throughout the whole minimization process, it's a very simple and straightforward method that has not only an economic effect (saves the cost) and also an environmental side to it: reducing the CO₂ emissions. The problem with this tool is that in the structural design stage, we have to increase the productivity of rebar work and reduce the rebar loss rate.

The question is weather is it applicable in Morocco is not an issue because it does not depend on the country itself but the enterprises and their wiliness to use the CWM. Besides that at the construction site, it's hard to precisely have the technician and workers to make those cuts because the results may not be practical to begin with.

As a future civil engineer, I would pursue to improve the algorithm at hand because it saves a lot of money and make the construction more sustainable for future generations. It is widely recognized that architecture, engineering, and construction industry significantly affect the environment: we must protect our PLANET.

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